Sustainable Energy Technologies and Assessments 20 (2017) 78–87

Contents lists available at ScienceDirect

Sustainable Energy Technologies and Assessments

journal homepage: www.elsevier.com/locate/seta

Original article

Assessing the technical impact of integrating largescale photovoltaics to the electrical power network of Bahrain

Gobind Pillai [a,*], Husain Yaqoob Naser [b]

[a] School of Science and Engineering, Teesside University, Middlesbrough, UK
[b] Electricity Transmission Directorate, Bahrain Electricity and Water Authority, Bahrain

ARTICLE INFO

Article history:
Received 9 August 2016
Revised 7 January 2017
Accepted 27 February 2017

Keywords:
Photovoltaics
Grid integration
Power flow
Fault analysis

ABSTRACT

Electricity demand of Bahrain is met almost entirely by gas turbine power stations at present. The peak demand growth rate of around 6.5% per year necessitates installing new generation in near future. Bahrain's rich natural solar resource could be exploited to meet this need. However, so far, no detailed studies on the grid integration of large scale photovoltaics (PV) systems have been carried out. Potential impacts of integrating a 1 MW PV plant to the power network of Bahrain is examined in this paper by means of a systematic modelling analysis using PVsyst and PSSE. Results demonstrate how PV systems can exploit the advantage provided by the weather of Bahrain to match the peak demand. Other concerns addressed in this work are impact of PV generation during times when electrical power network is more susceptible to voltage limit violations and impact of fault current contribution from the PV plant to the security of the network considered. The overarching view from the results of these grid integration studies is that the outlook for network integrated PV in the future In Bahrain is positive. It is hoped that the results of this work would inform Bahrain's utility's policies on PV systems.

Introduction

Bahrain is a country where the electricity demand is growing. The annual electricity demand rapidly increased in the recent years and reached a 10% growth rate in 2014. A large portion of the demand is due to the domestic sector which accounts for about 48% of the annual electricity demand. In addition, the peak load of Bahrain which normally occurs between June and September reached 3335 MW for 2015 with a growth rate of 5.8% over the previous year [1,2]. An increasing in the electricity demand means that the generation capacity has to be expanded to keep pace with it. Bahrain has five power generation plants with capacity of around 4 GW, all of which depend on gas as the fuel for operation. An increase in the amount of gas turbine power stations will result in increased in CO_2 emissions [3].

The GCC is made up of six major oil and natural gas producing countries namely Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. Recently, the countries of GCC have started introducing serious plans to increase the number of renewable energy projects in order to diversify their energy resources both in technical and economic terms and help them towards sustainability by improving energy efficiency and reducing CO_2 emissions [4,5]. Bahrain has already announced a plan that by year 2020 the contribution of renewable energy to electricity generation will be 5% of the total generation capacity. Solar energy has received more attention as compared to other renewables [6]. This is a step in the right direction as the cost of traditional electricity production in Bahrain - 28 fils per kWh (0.07 USD/kWh) which compared to the average levelised cost of PV generation from GCC countries (0.05–0.10 USD/kWh) is actually more expensive [7]. In comparison the cost of generation for Saudi Arabia is 0.099 USD/kWh and Kuwait is 0.0133 USD/kWh [8] which makes the former more attractive and latter less attractive for PV as compared to Bahrain.

The Middle East and North Africa region where Bahrain is situated has some of the best of solar insolation in the world. The average daily solar radiation of GCC countries alone is about 6 kWh/m^2 with more than 80% clear sky during the year [9]. It is clear that the countries with high irradiation like Bahrain has a good opportunity

Abbreviations: EWA, Electricity and Water Authority, Bahrain; PV, Photovoltaic; GCC, Gulf Co-operation Council; PVGIS, Photovoltaic Geographical Information System; GHI, Global Horizontal Irradiation; JRC, Joint Research Centre of the European Commission; STC, Standard Test Conditions; NOP, Normal Open Point; RMU, Ring Main Unit; LV, Low Voltage; PR, Performance Ratio.

* Corresponding author.
E-mail address: G.G.Pillai@tees.ac.uk (G. Pillai).

http://dx.doi.org/10.1016/j.seta.2017.02.019
2213-1388/

Nomenclature

I	current supplied by PV module (A)	k	Boltzmann constant (J/K)
I_{ph}	photocurrent (A)	Tc	effective cell temperature (K)
I_O	inverse saturation current depending on the temperature (A)	R_{sh}	shunt resistance (Ω)
q	charge of an electron (C)	G	effective irradiance (W/m^2)
V	voltage at the terminals of the module (V)	G_{ref}	reference irradiance (W/m^2)
R_S	series resistance (Ω)	μI_{SC}	temperature coefficient of photocurrent (short-circuit current) (/°C or /°K)
N_{CS}	number of cells in series	$T_{C\ ref}$	reference cell temperature (K)
γ	photodiode quality factor	E_{Gap}	energy gap of the semiconductor material (eV)

to invest in photovoltaic (PV) technology [10]. PV systems have very low maintenance cost compared to conventional generation because of the reduction in the number of moving parts [11]. Another main advantage of PV is its modularity which makes its applications easier and more widespread in the end-user market [12]. The cost of manufacturing PV modules is following a decreasing trend and is expected to decline more in the coming years [13]. The low maintenance cost, lowering cost of modules and CO_2 emission free nature of PV systems should promote PV installation in countries like Bahrain which a high electricity generation has cost and considers the climate change problem seriously.

Many studies exploring the electricity generation potential, economic viability and CO_2 emission reduction capacity of PV systems have been conducted for different countries in the GCC region. Mansouri et al. [12] looked at the case of Saudi Arabia in the context of growing energy consumption and consequent CO_2 emissions and examined the emission reduction potential of PV systems along with carbon capture and storage. Reiche [14] comments on the energy policies of GCC countries and demonstrates how they have recently adopted a more pro-active approach towards addressing environmental issues in their energy sectors. Radhi [15] examined the value of smaller scale building integrated de-centralised PV systems for GCC and highlights the need for financial incentives to promote their uptake. Alnatheer [16] shows how expanding electricity generation by including wind and PV systems can result in a societal least-cost plan for Saudi Arabia. For Bahrain, given the already high generation cost compared to Saudi the impact on the societal cost should be much more positive. Ramadhan and Naseeb [17] examined the costs and benefits of PV systems in Kuwait and demonstrated that the true economic cost of a unit of energy from PV systems will decline significantly when the savings in conventional generation and the cost of reducing CO_2 emissions are accounted for. The technical and economic potential of PV systems for the climate of countries in GCC was assessed in [8,18,19].

The policy options for renewable energy was examined in [20] for Abu Dhabi and highlights the importance of taking into consideration both electricity generation and demand which is taken care of in this study. The development of an integrated resource planning framework for expanding Saudi Arabia's electricity generation option was presented in [21]. The author highlights the need for the availability of renewable energy technology potential assessments for using in generation expansion planning. One of the reasons for the lower number of PV potential assessments was the need to formulate solar resource estimation methodologies, an example of this, for Saudi Arabia, is presented in [22]. This difficulty was alleviated to a large extent with the availability of PVGIS which is used in this study. Unlike using independent PV potential estimation software such as HOMER, RETScreen, and System Advisor Model in combination with a solar database such as NREL and NASA. PVGIS is a geographic information system that does an integrated mapping of data essential for PV resource estimation (climate, estimated solar electricity generation, optimum inclination angle of the PV modules) into one online tool.

The design of a pilot 36 kW PV system and observations from its first year of operation integrated to the low voltage (0.4 kV) network of Abu Dhabi is reported in [23]. The negative effect of weather conditions of the location especially accumulated dust deposition on the PV system power outputs was demonstrated. The performance PV system under the weather of Doha is examined in Touati et al. [24] using a customized measurement and monitoring system. They point out the impact of relative humidity in addition dust on the efficiency of PV generation.

The system design, specifically optimal sizing of the grid-connected PV inverter with respect to the size of the PV array was discussed in [25] with regards to unmet demand, surplus generation, fraction of renewable electricity, net present cost and CO_2 emissions for Saudi Arabia. Al-Sabounchi et al. [26] looked at the potential impacts of integrating PV systems to the electrical power network of UAE base on two pilot systems rated at 36 kW and 9 kW and highlighted the importance of basing the PV system location and size based on the electricity demand profile and the PV generation profile. Despite similar solar resources, the type of main conventional generation plants, network configuration, cost of generation transmission and distribution varies from country to country. There were no studies in the literature which specifically looked at the potential impacts of integrating large scale PV ystems to the electrical power network of Bahrain. The research presented in this paper aims to address this gap in knowledge.

Not withholding its positives, the design and network integration of PV systems especially at the large scale is not without challenges and ambiguities. The warm climate and the high temperature at the PV module surface may lead to a decrease in the module performance [27]. PV generation operates in a direction opposite that of conventional power flow this may result in changes to network voltage profiles and in certain cases violation of node voltage limits, a reduction or an increase in line losses, and increased fault current levels [28]. Thus, the integration of large scale PV systems to electrical power networks, could have positive or negative impacts on the network depending on the network configuration and the solar resource of the location. In order to formulate appropriate policies and guidelines, utilities and government agencies require data on the impacts of network integration of PV systems under the climate of the country. Installation of PV systems in countries like Bahrain with load peaks in the afternoon offer the opportunity for using PV generation for natural daily peak load matching. There were no detailed studies done so far to assess the impact of network integration of large scale PV systems in Bahrain. The potential impacts of integrating a 1 MW PV plant to the power network of Bahrain is examined in this paper by means of a systematic modelling analysis using PVsyst and PSSE. The main objective of this work is to inform the design of large scale PV systems in Bahrain and the utility policies on network integration of these systems.